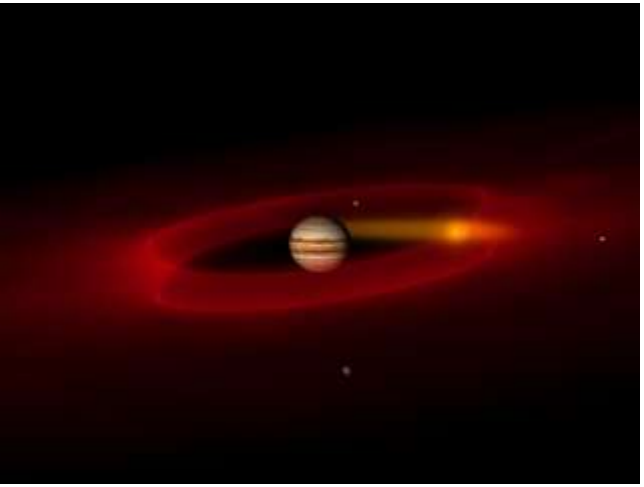
Radiation-Hard Cameras for Jupiter System Science



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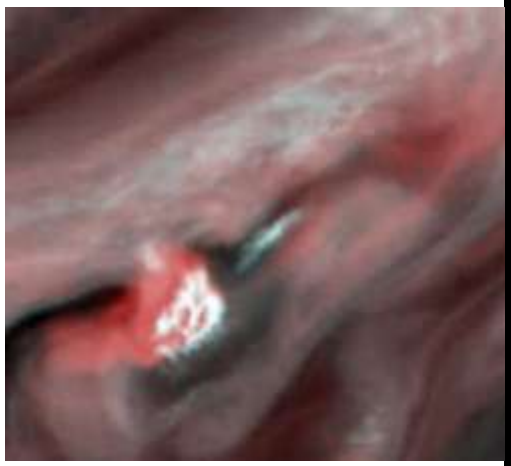
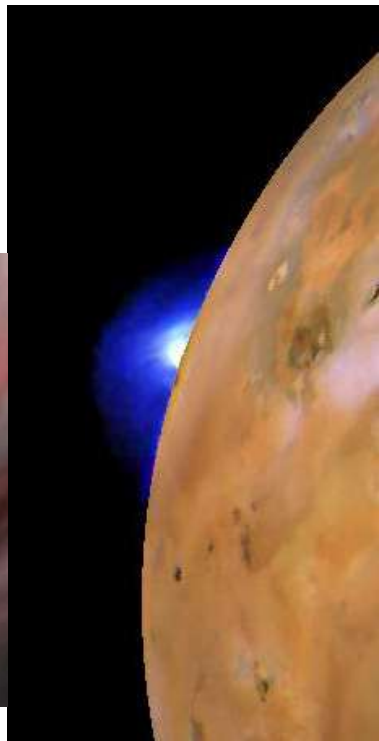
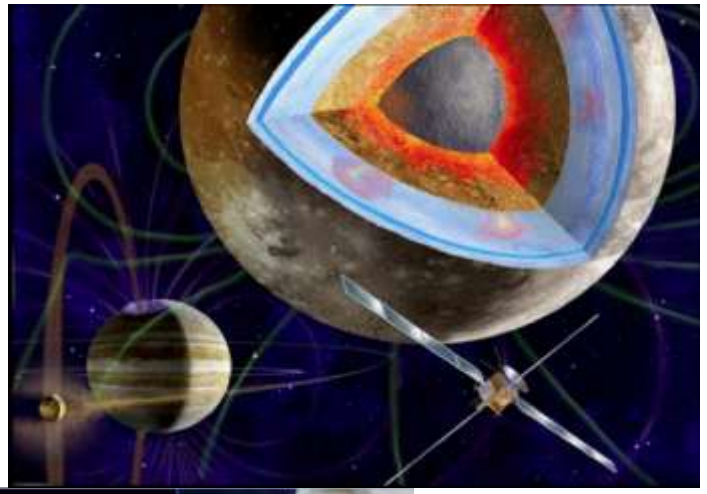




Future Jupiter missions needing rad-hard cameras



- ESA's JUICE
  - launch in 2022, Jupiter arrival 2030

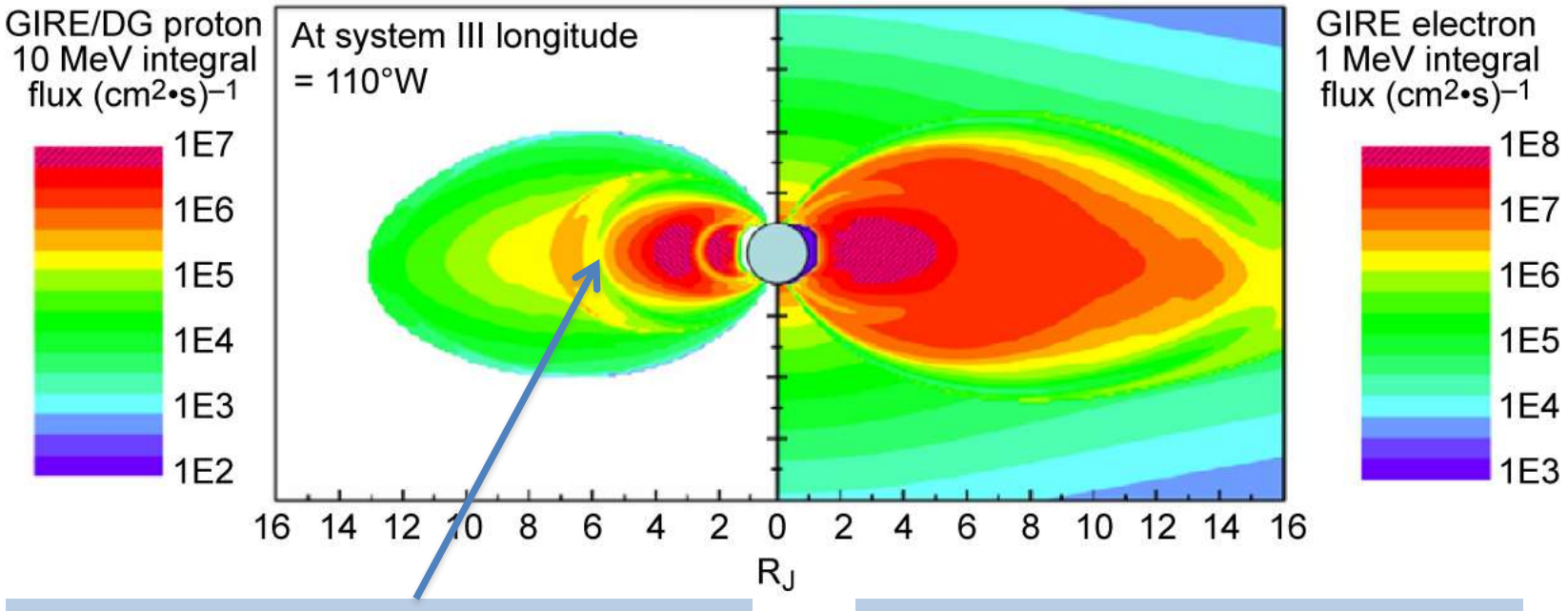
- NASA Europa mission concepts
  - Europa Orbiter
  - Europa Clipper
    - multiple flybys
  - Europa lander

- Io missions
  - Io Volcano Observer (IVO: Discovery 2010 proposal)
  - Io Observer (recommended for New Frontiers in Vision and Voyages Decadal report)

Two Radiation Challenges

- **Total Ionizing Dose (TID)**
  - Cumulative over mission; damage to components
- **Radiation-induced noise**
  - Esp. when close to Jupiter; no damage

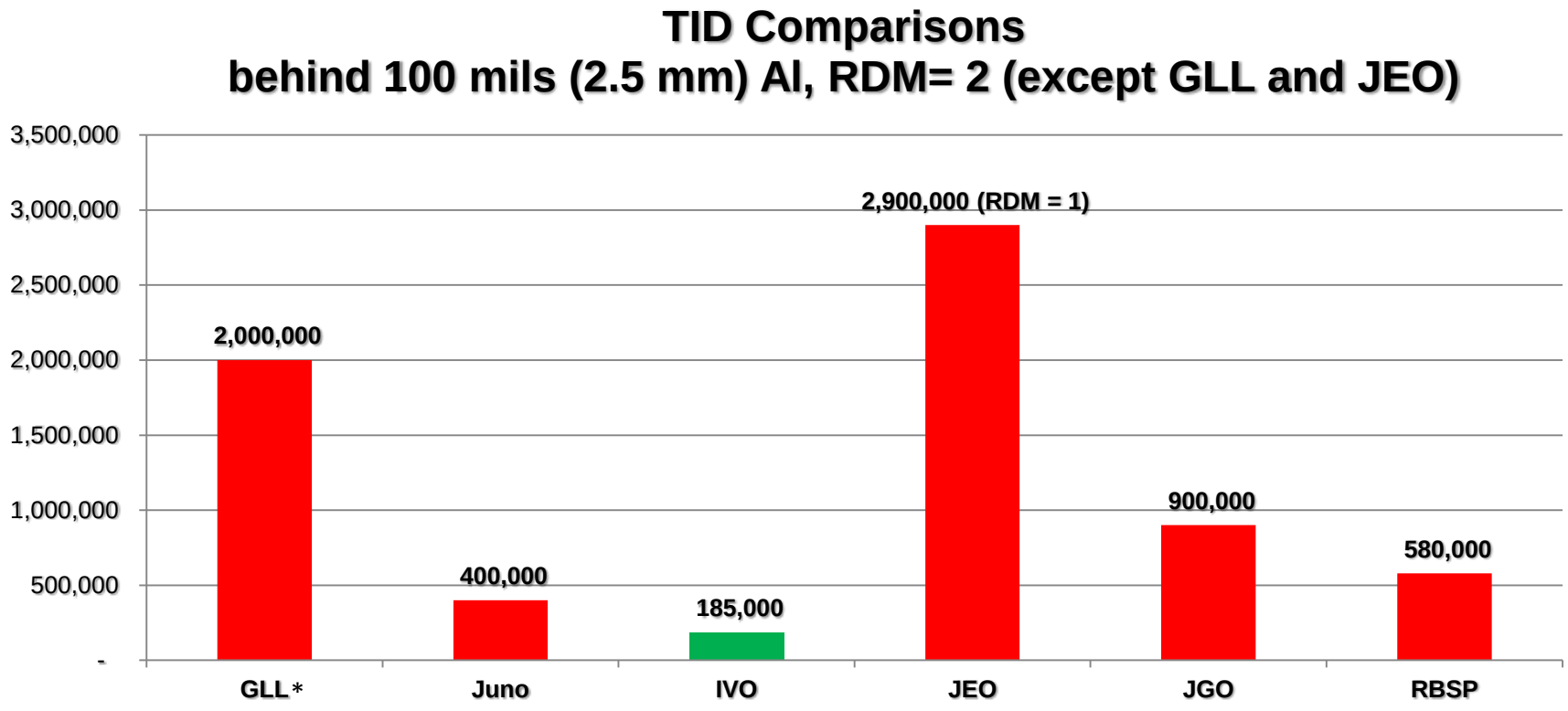
JPL model of Jupiter's radiation belt (I. Jun) -- from Europa book chapter by Paranicas (2009)



Io (and other satellites) typically carve out a notch in the proton belt

The electron belt is much less organized by the satellites

Radiation: Comparison of Jupiter Orbiters (+ RBSP)

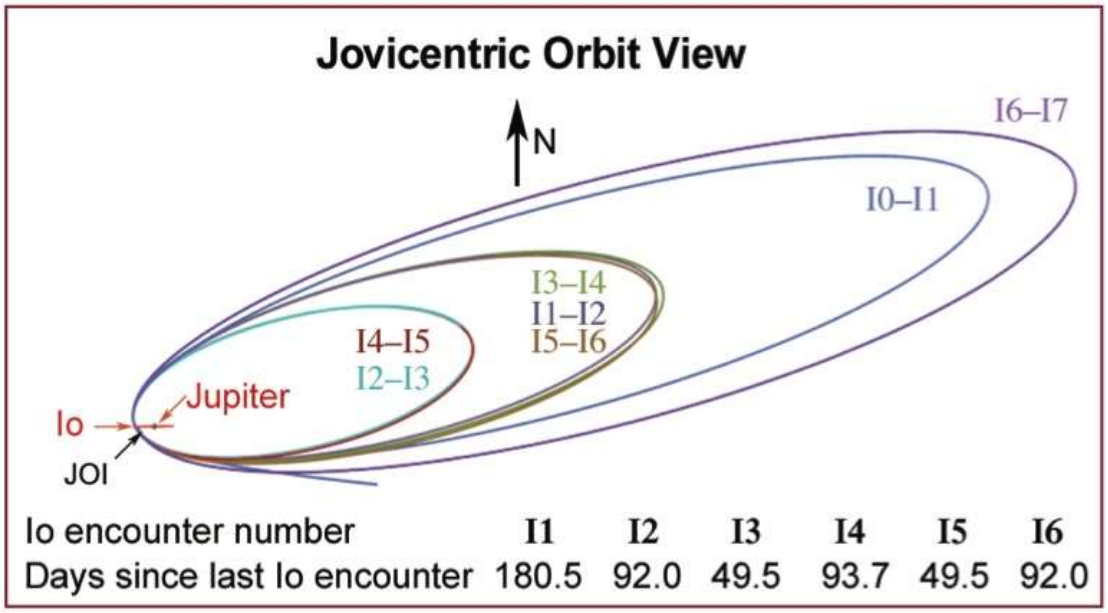


* Actual (modeled) TID for full GLL mission

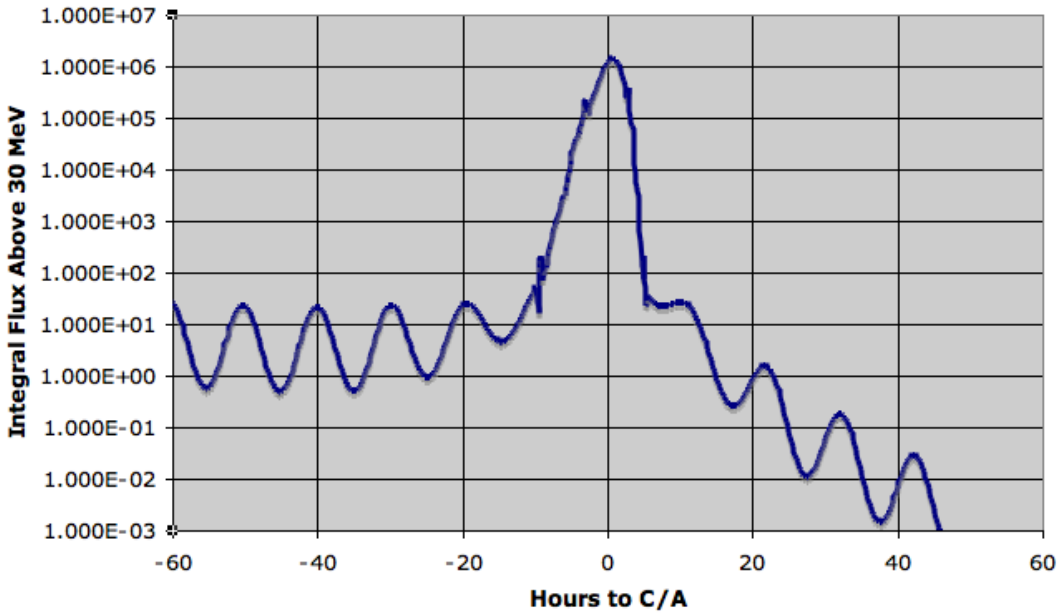
JUICE and new Europa missions fall in-between JGO and JEO in total dose.

IVO Orbit optimized to minimize total dose

- Orbit inclined ~45º to Jupiter's orbital plane
- Nearly north-south flybys of Io has significant advantages
  - Minimizes total dose per flyby
    - ~10 krad per flyby (v. 85 for JEO)
    - S/C only spends ~15 hrs/flyby in the intense radiation
    - >20 km/s flyby speed is a challenge
  - Can get closer to Io with low radiation noise for imaging faint emissions



Io encounter number	I1	I2	I3	I4	I5	I6
Days since last Io encounter	180.5	92.0	49.5	93.7	49.5	92.0



Basic Concept for Radiation-Hard Camera

- Electronics must survive TID
- Must shield detector for transient noise so TID may be low (only tens of krads with 1 cm Ta shielding)
  - CMOS or CCD can survive TID, with increasing dark current for CCD (mitigate by cooling detector)
- To minimize transient noise, get data off the detector as fast as possible
  - This is where CMOS or Active Pixel Sensor (APS) has a great advantage over CCDs (50x faster readout than Galileo SSI)
  - Advantage of CCDs is on-chip Time Delay Integration (TDI) and pixel binning
  - But CMOS can use digital TDI if read noise is low
  - Need a capable (but low power and mass) Digital Processing Unit (DPU)
    - APL experience: CRISM, etc.

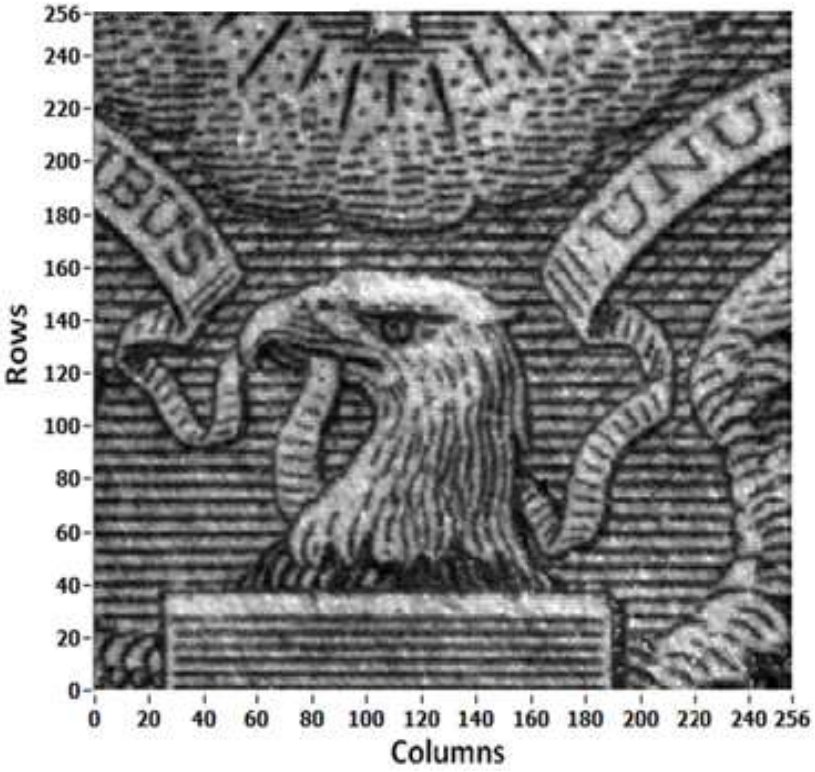
Two ways to achieve high SNR with transient radiation noise

- Noise builds up as a function of SQRT (noise intensity)
- Method 1 is to use long exposure times so signal eventually wins the war over noise
  - Strategy of Galileo SSI (framing mode), aided by slow flybys of Io and Europa
  - But JUICE, Europa Clipper, and Io missions have faster and closer flybys and must use short exposure times
- Method 2 (with short exposure times) relies on reading data off the chip as fast as possible to minimize radiation noise, plus off-chip TDI and binning
  - APS technology needed

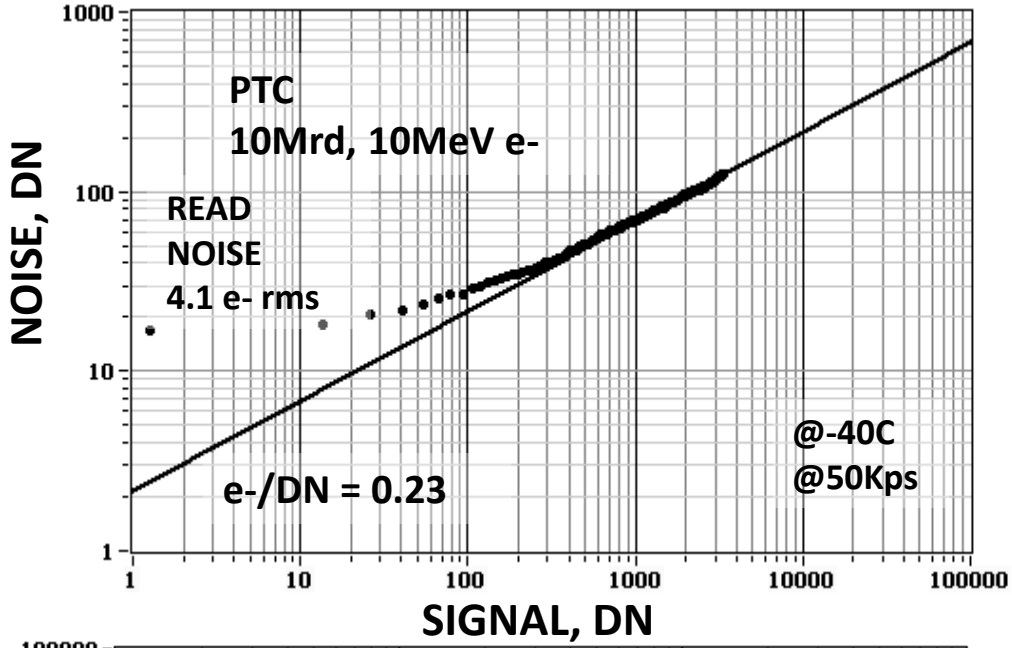
CMOS Detector

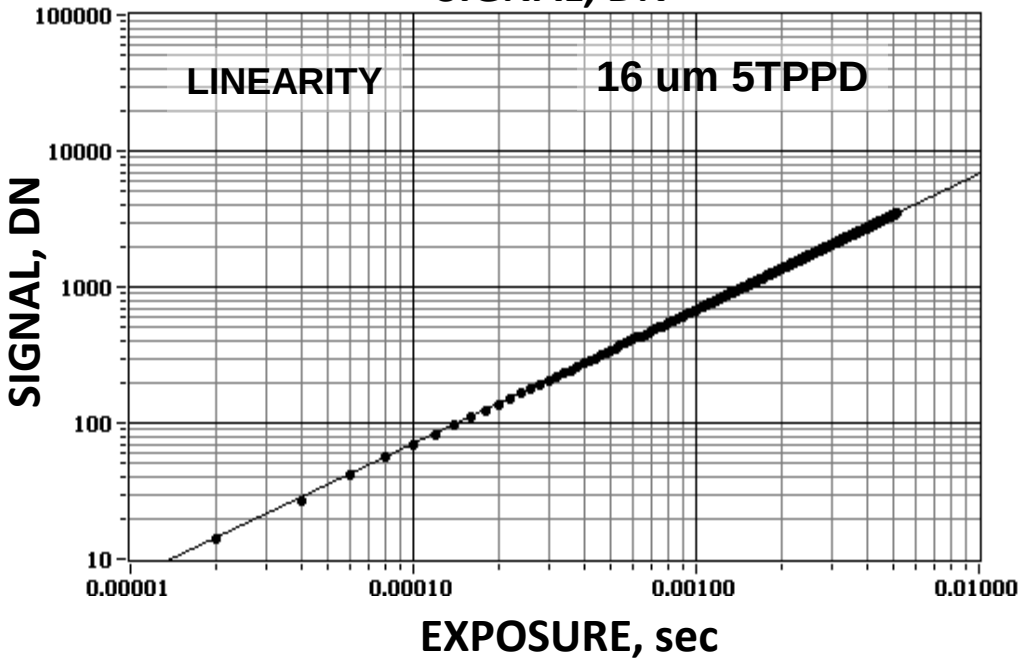
- Custom SRI Sarnoff CMOS Active Pixel Sensor
- TowerJAZZ 0.18 um custom process
- 1920 x 2048 non-stitched array of 10 x 10 micron pixels partitioned into 960 x 1024 quadrants
  - Identical to that used by SoloHI on Solar Orbiter, except we need backside illumination for improved QE
- Four 10 MPPS readouts with CDS and analog pipeline to eliminate row settling delay
  - <15 e- read noise at this fast readout rate
- 6TPPD Pixel
- 15 micron epi

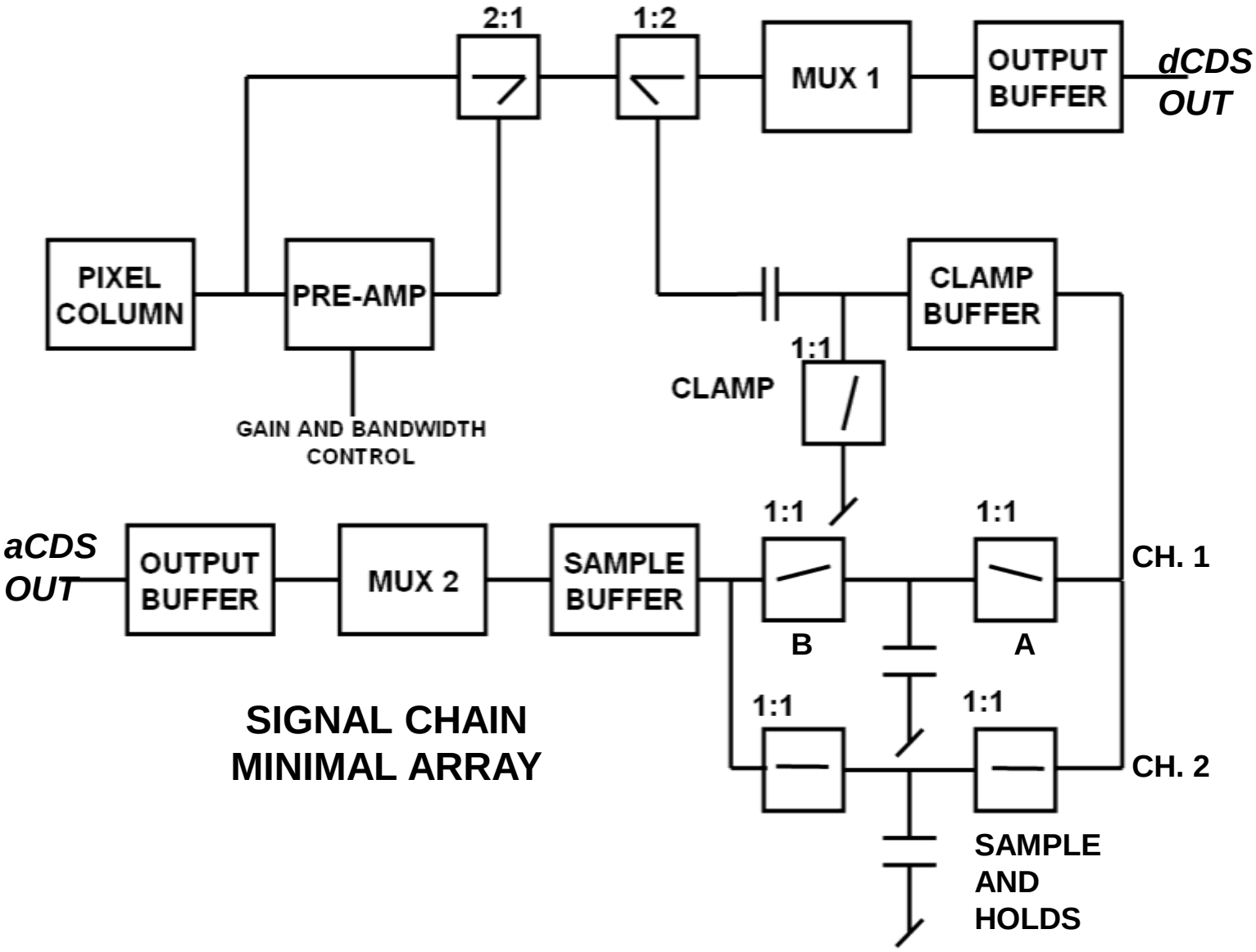
CMOS performance is excellent even after 10 Mrads of 10 MeV e-, but signal chain wasn't previously tested



10 Mrd, 10 MeV e-

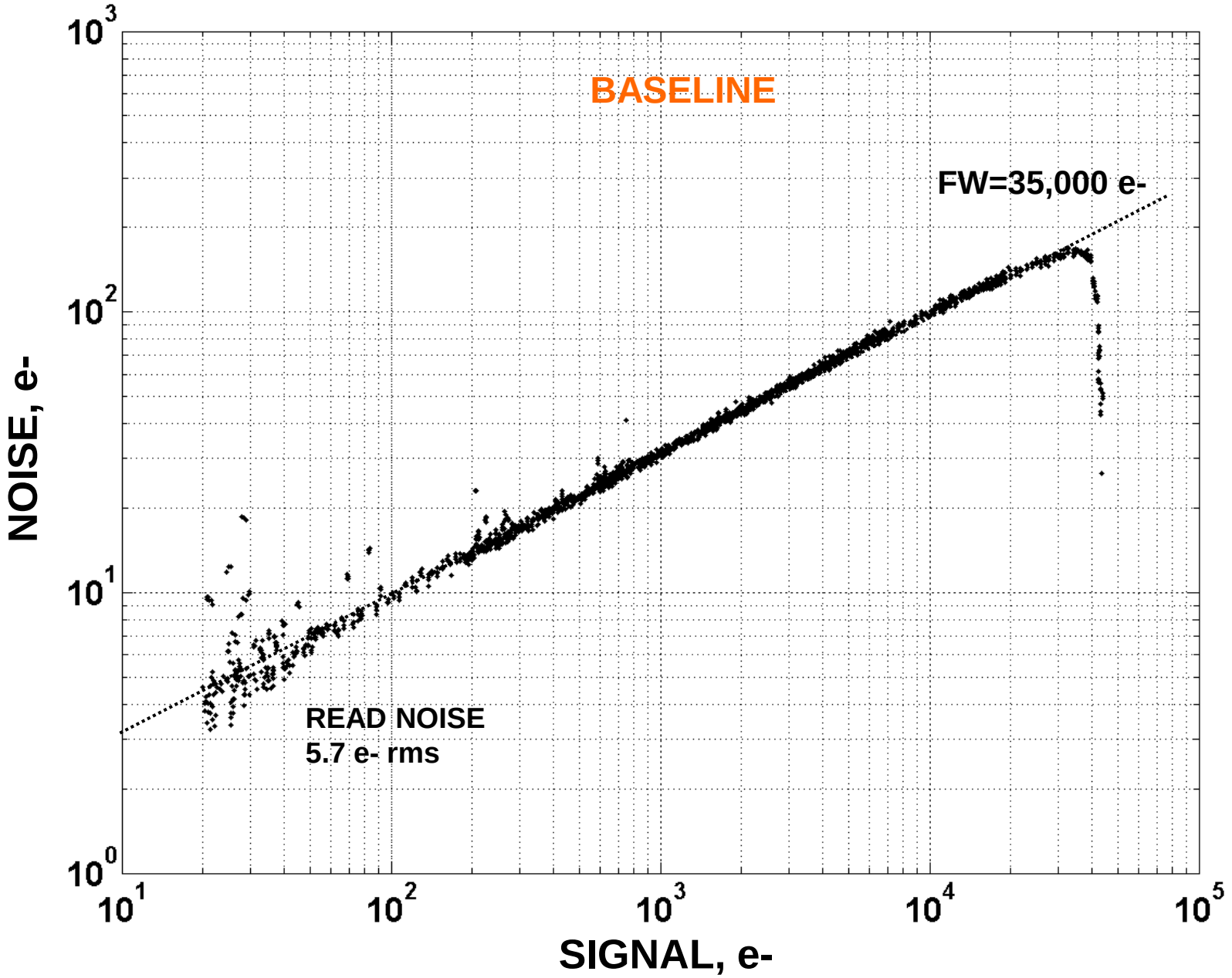






SIGNAL CHAIN MINIMAL ARRAY

SIGNAL CHAIN: No problems after 1 Mrad with 2MeV e-



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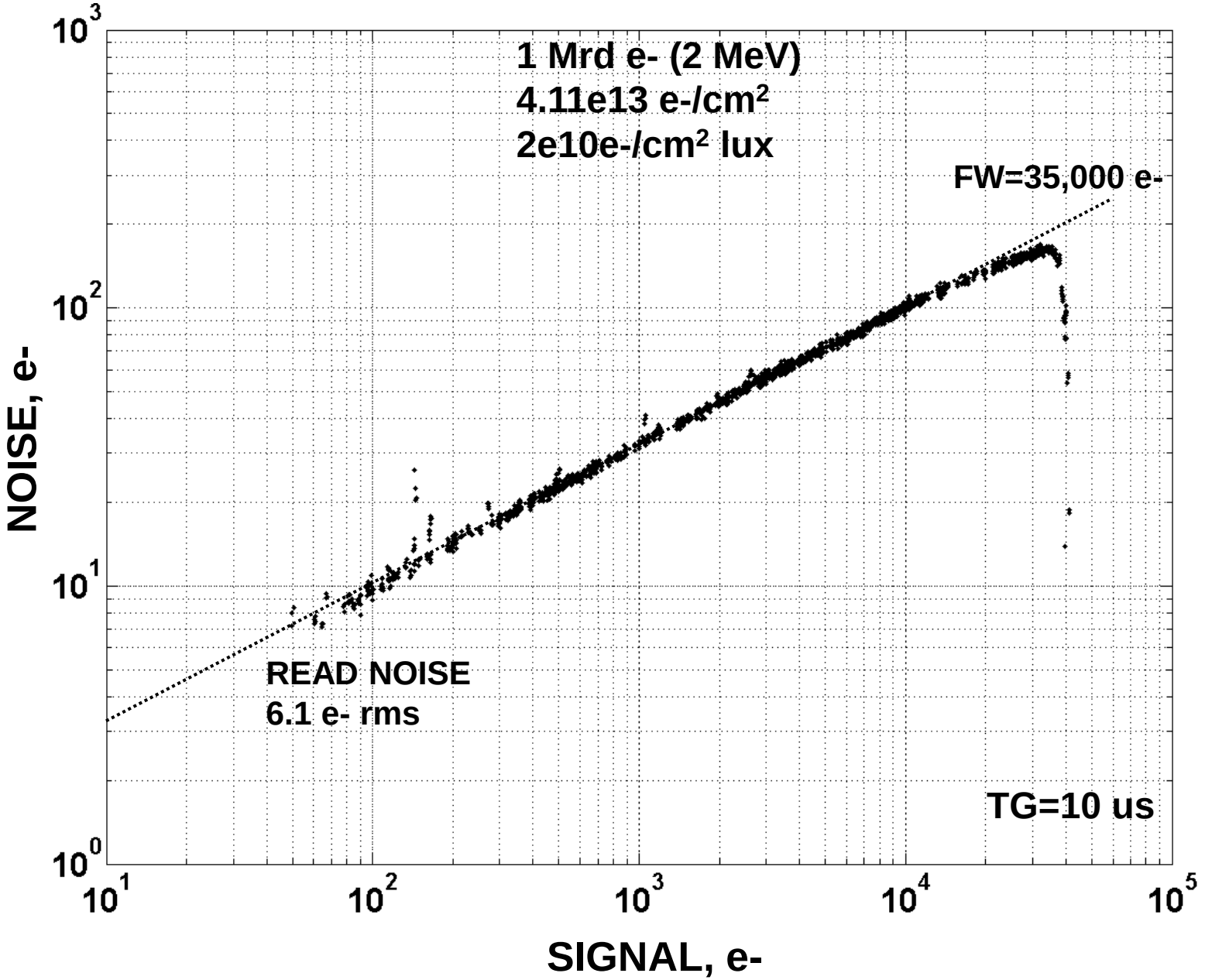
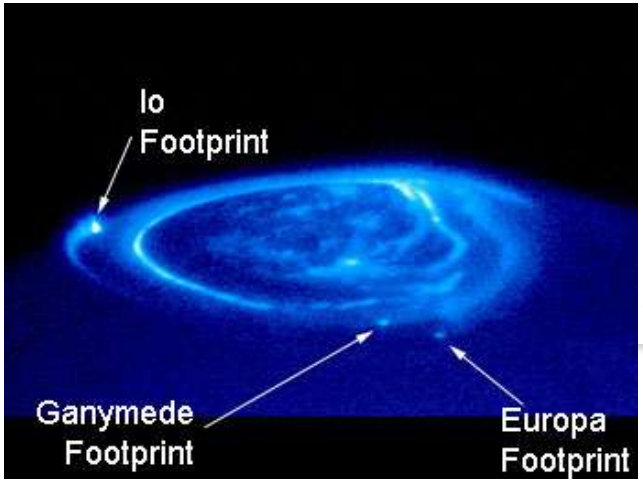
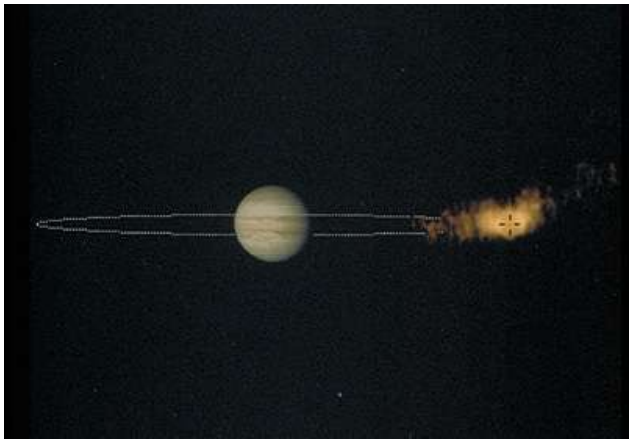


APS-DPU system enables other capabilities

- Framing or pushbroom modes
- Very high frame rate for movies of dynamic phenomena
- Digital TDI (pushbroom or framing)
  - including diagonal TDI with interpolation
  - Image very faint targets (aurorae, rings) with TDI and low read noise
- Super-resolution imaging
- Pushbroom stereo (WAC), including diagonal stereo
- Pushbroom color
  - combined with TDI, diagonal imaging, stereo
- Median filtering to remove noise hits prior to summing images (TDI or binning)

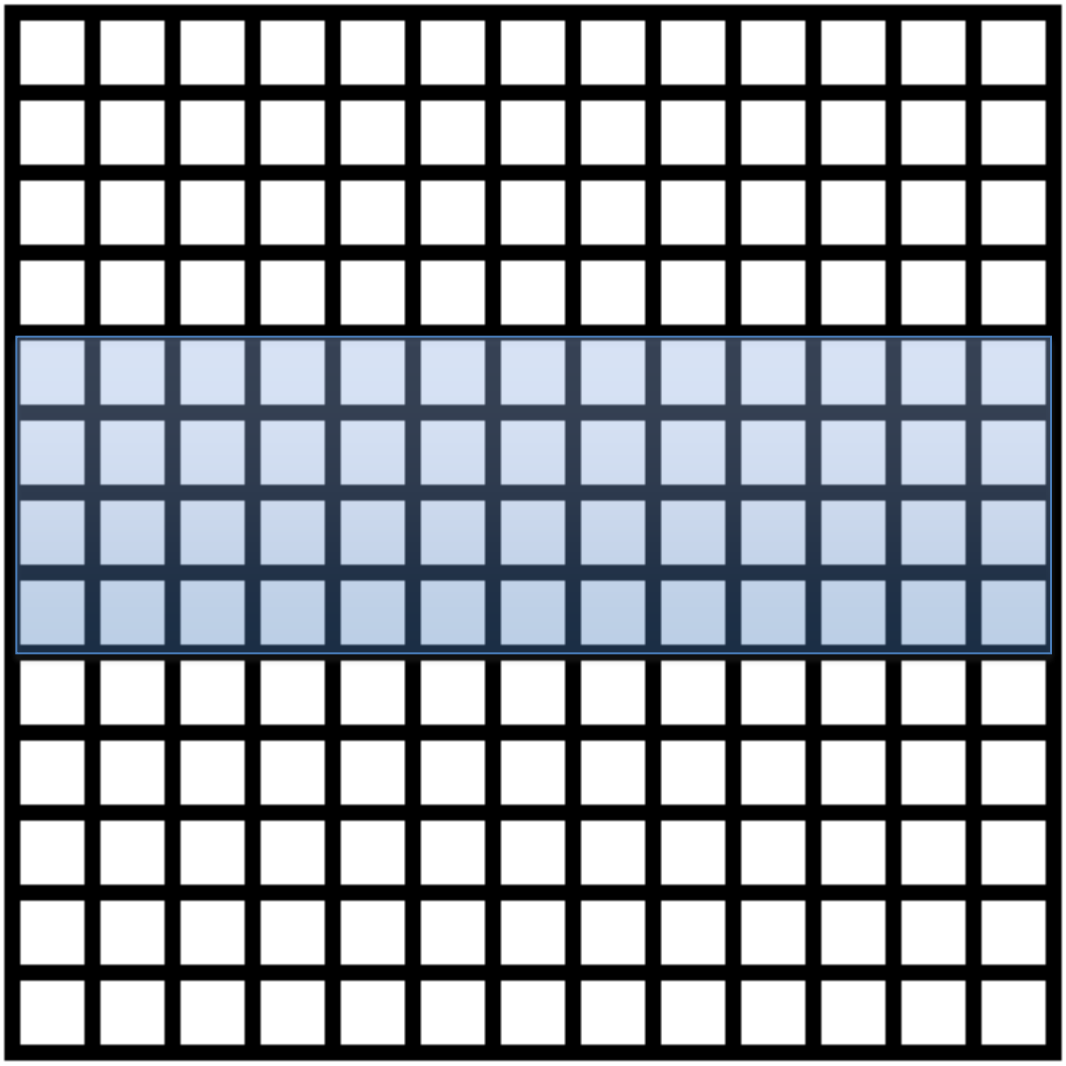




How standard digital TDI imaging works

Pushbroom with 4 TDI lines (and a really small array) and with motion aligned to columns. Read out N sample x 4 line frame every time scene has moved 1 line, shift and co-add lines in DPU.

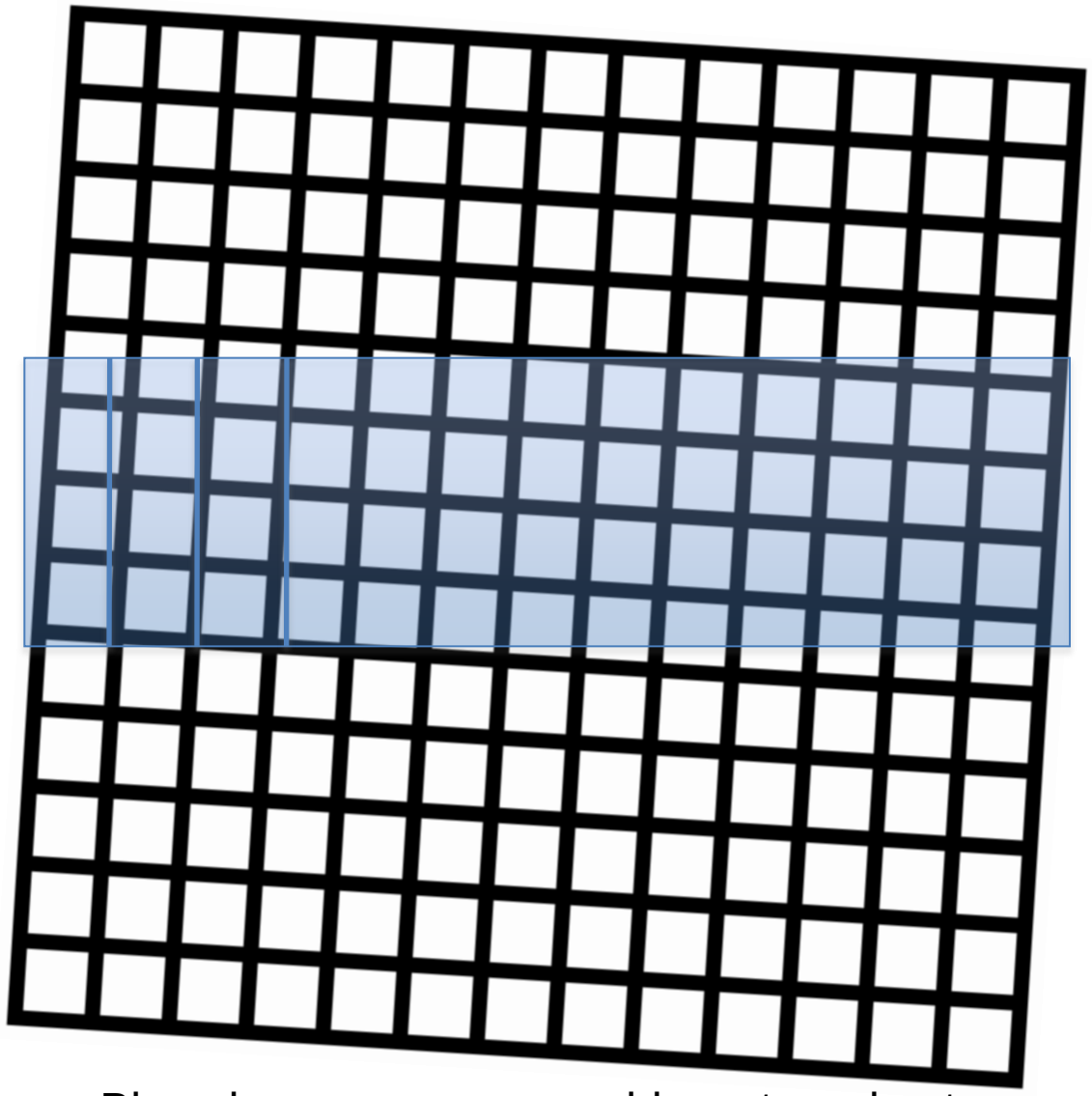
Image motion
(or reversed)



Blue shows area of chip to read out

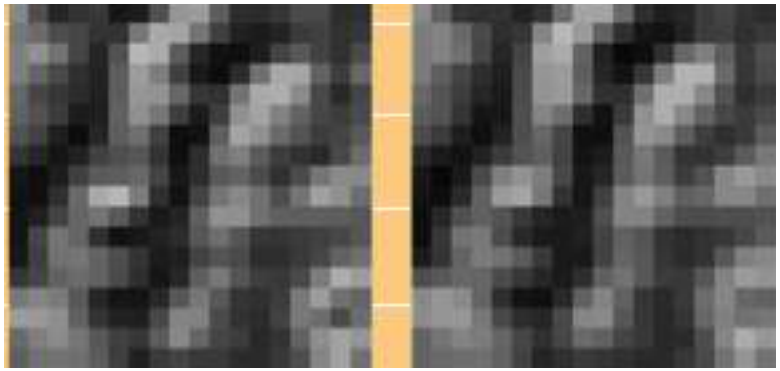
Standard TDI with scene moving at a slight angle results in cross-track smear, proportional to angle and #TDI lines.

Image motion (or reversed)

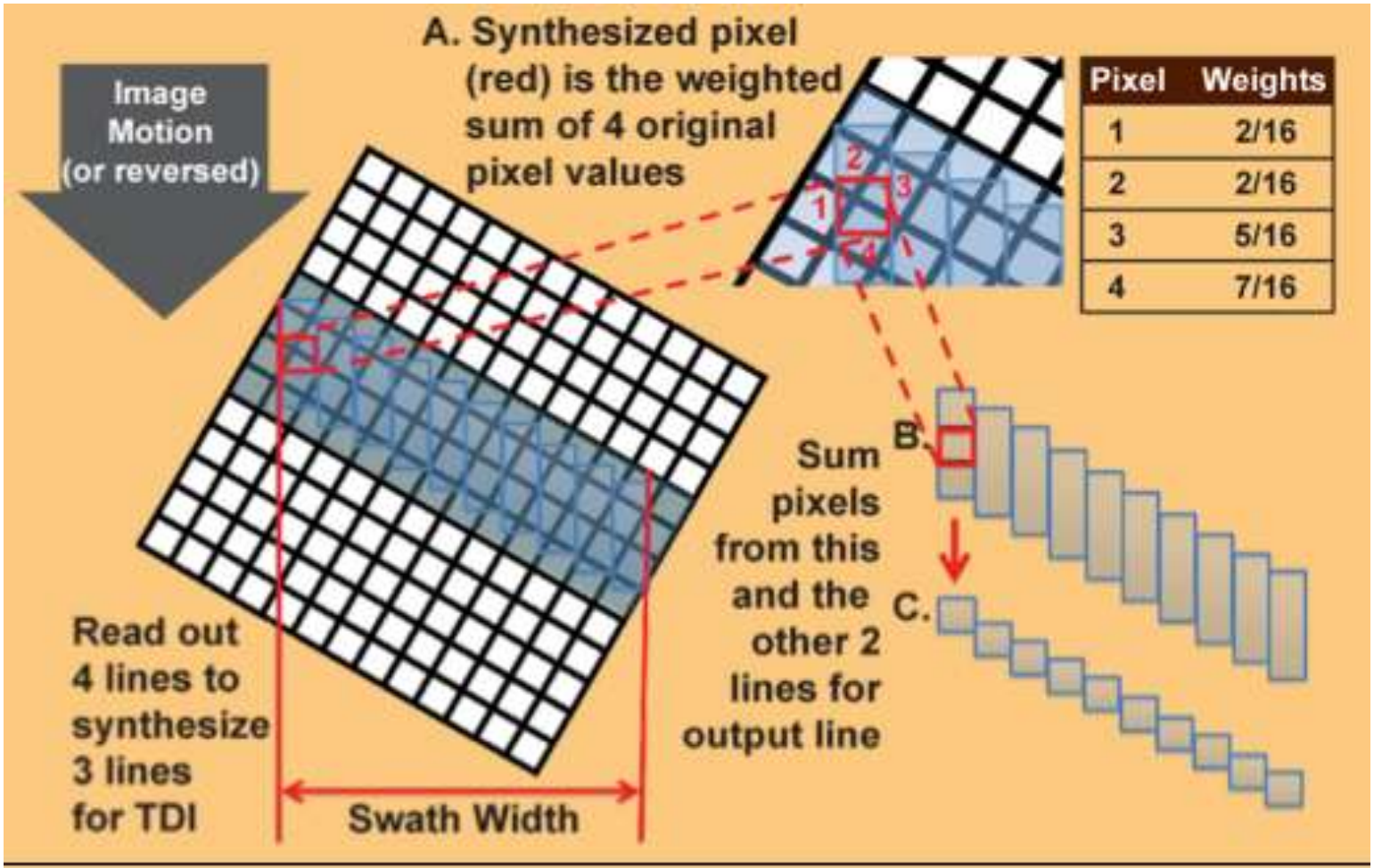


Blue shows area you would want read out.

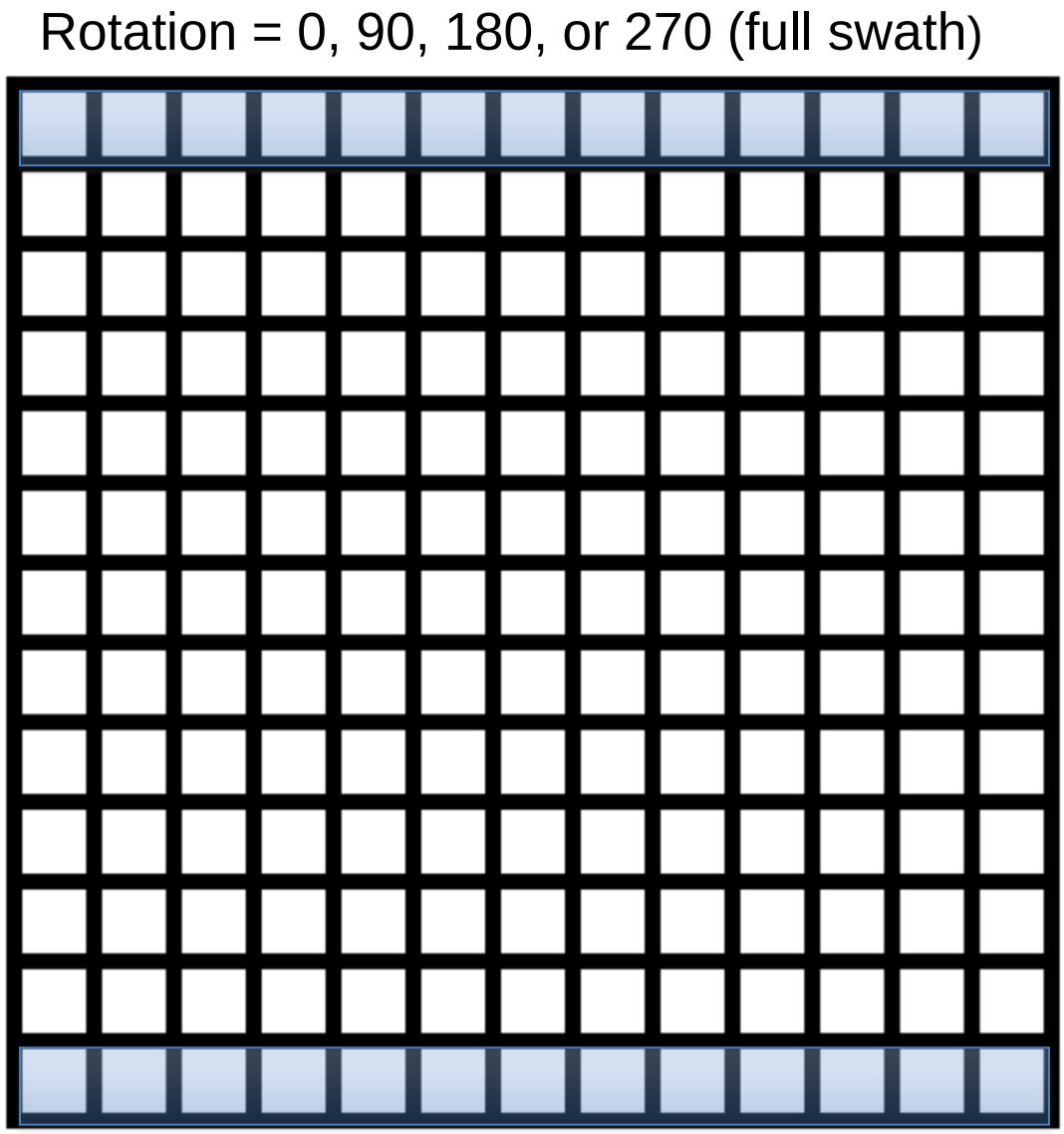
Diagonal TDI with pixel interpolation to minimize loss of resolution



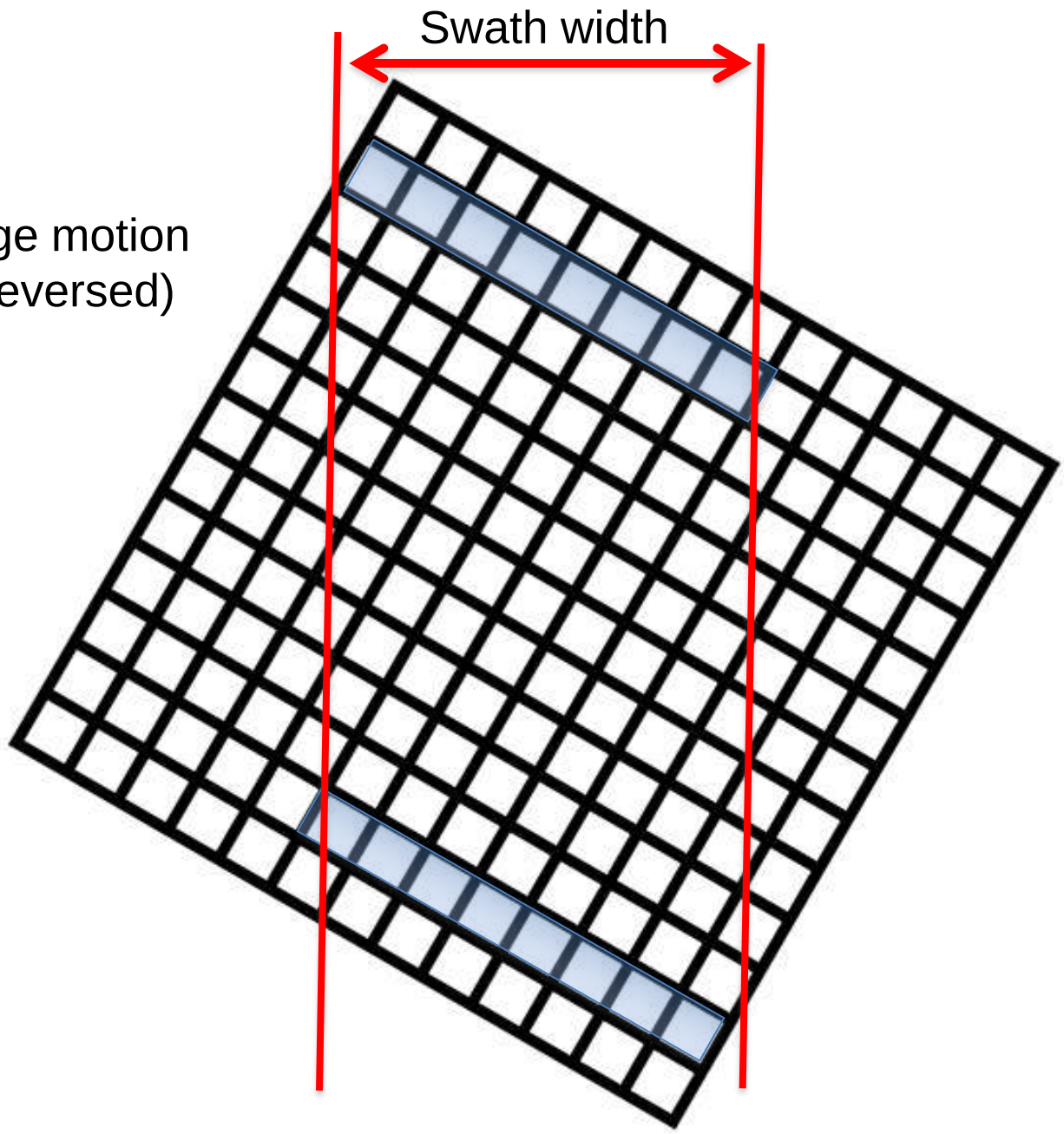
Before (left) and after interpolation



Pushbroom stereo mapping with a Wide-Angle Camera (WAC; FOV ~45°)



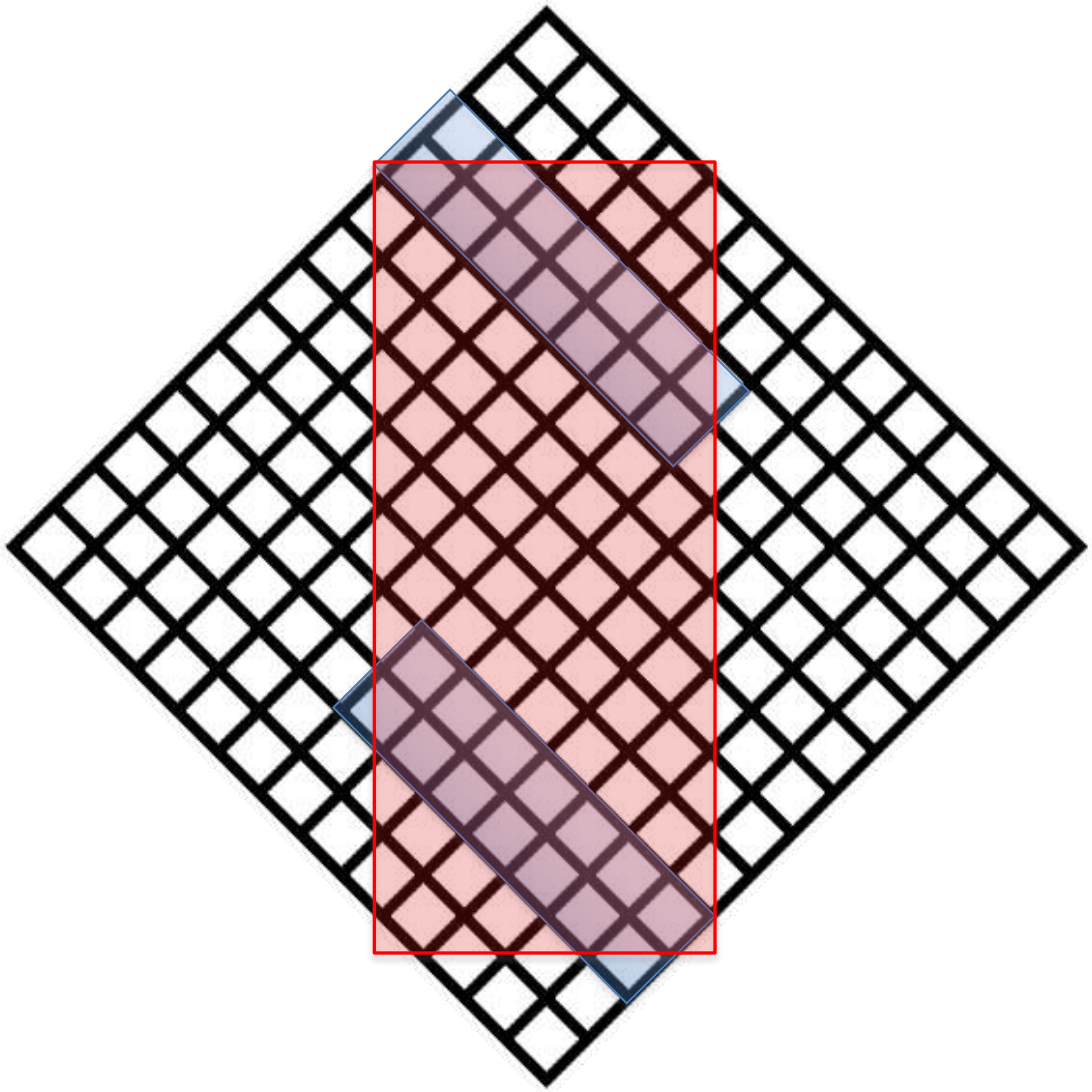
Diagonal Stereo



Rotation =
30˚ , 120˚ ,
210˚ , or 300˚
(swath reduced
~45%)

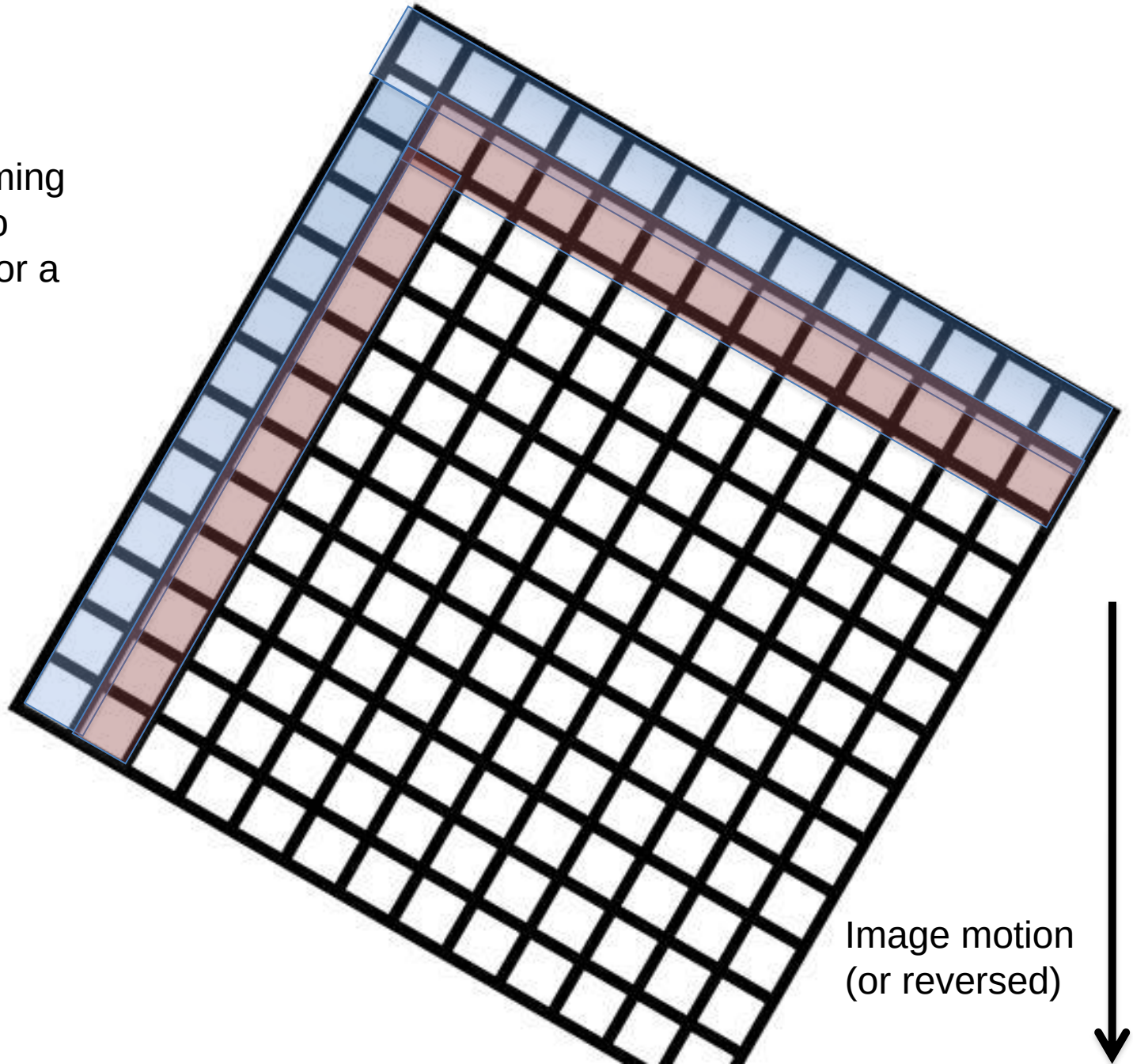
Worst case 45° rotation

No overlap (or just the corner pixels) unless we move readout lines in from edges of the array

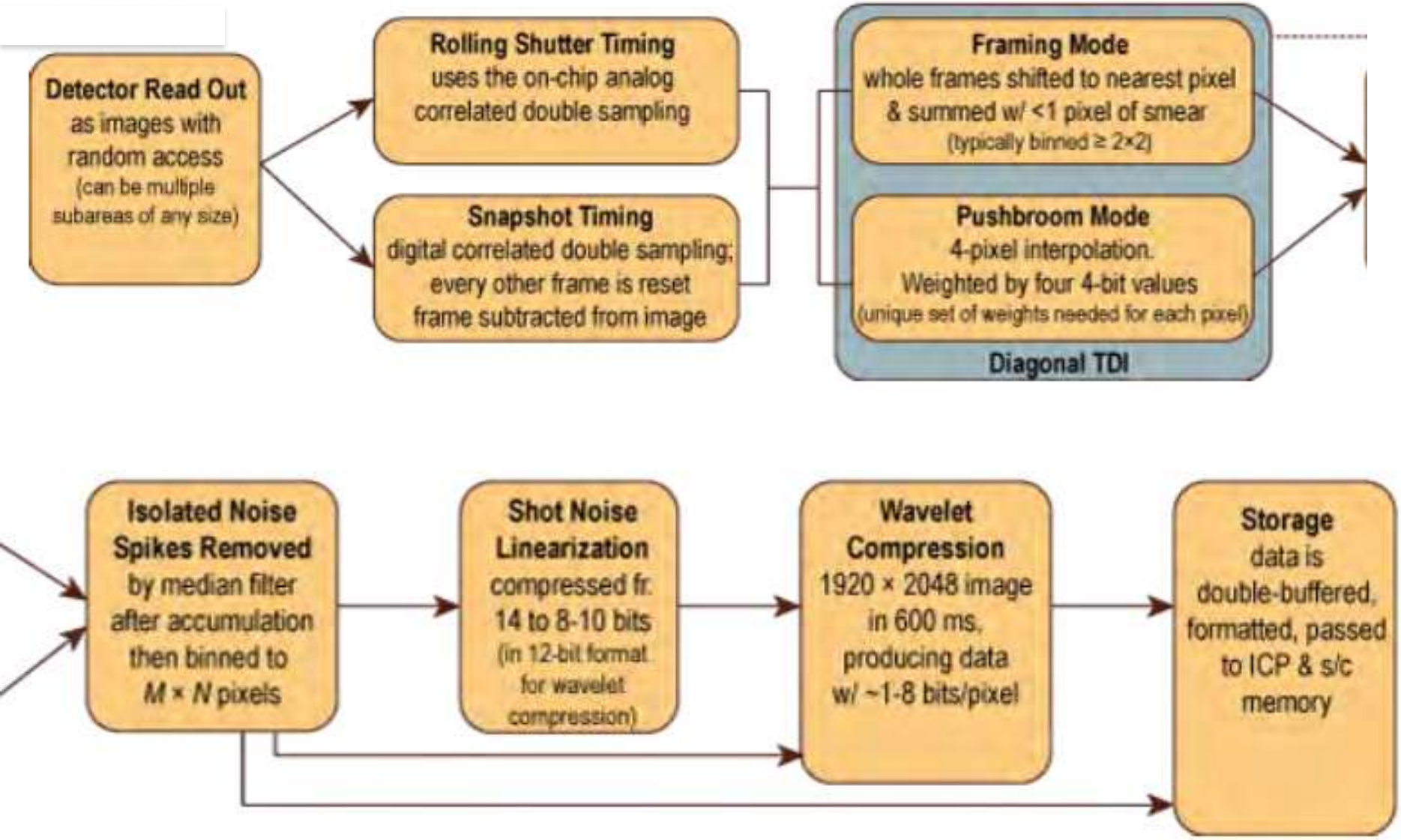


Use of color strips along edges for pushbroom color

Lose some framing area and stereo convergence (for a WAC).

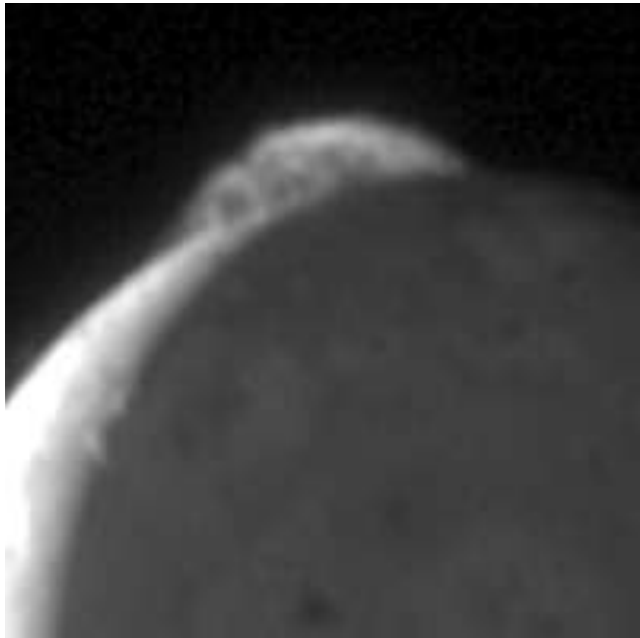


Imaging Steps, Detector to Storage



Summary

- Basic strategy for imaging in high-radiation environment:
  - Shielded APS, read data off detector very rapidly to minimize radiation-induced noise
  - Random access readout
  - Processing in shielded Digital Processing Unit (DPU)
- The APS-DPU system enables useful capabilities:
  - Framing or pushbroom mode
  - Digital time delay integration (TDI)
  - Diagonal imaging, with TDI, including along-track stereo
  - Filtering out noise
  - Super-resolution
  - Fast frame rates for movies



New Horizons movie of Tvashtar plume on Io

Thank You


THE MISSION CREEPS
Saturday, Sept. 29
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